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LLNL-TR-667185

JASPER Target Corrosion Inspection

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February 10, 2015

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This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

SYS-625 Fundamentals of System Engineering - Final Project

JASPER Target Corrosion Inspection

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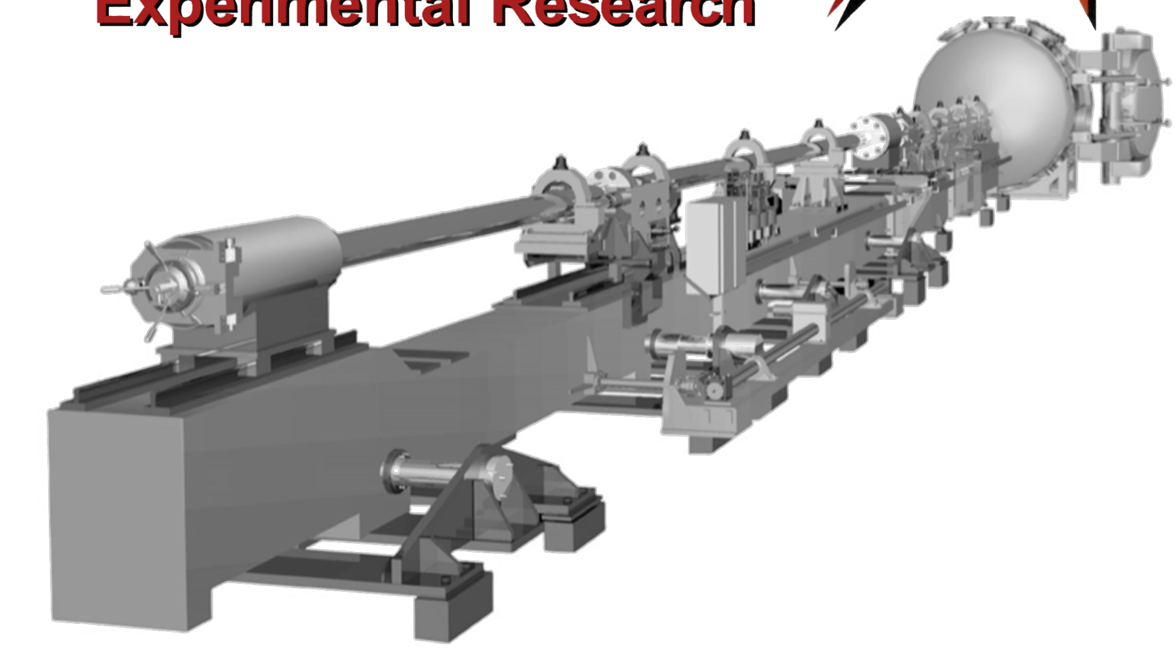
JASPER
Joint Actinide Shock Physics
Experimental Research



Revision 0

LLNL-TR-667185 **January 27, 2015**

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1.0 Executive Summary

1.1 Background

The JASPER (Joint Actinide Shock Physics Experimental Research) Facility is a key scientific tool for the National Nuclear Security Administration's (NNSA) Stockpile Stewardship Program (SSP). This program's combination of computer simulations, scientific theory and above-ground experiments has allowed the United States to maintain its nuclear deterrent for the past 20 years.

JASPER's experiments at the Nevada National Security Site (formerly the Nevada Test Site) have enabled Lawrence Livermore National Laboratory (LLNL) scientists to understand important properties and behaviors of plutonium and other actinides without conducting underground nuclear tests.

JASPER is a two-stage light gas gun, about 65 feet long, with a target chamber inside an 8-foot diameter containment chamber at the end.

In the first stage, a 10-pound piston is loaded into the pump tube breech along with up to 8 pounds of gunpowder. Once the pump tube breech plug is installed and the breech is sealed, a firing pulse is sent to the breech igniting the gunpowder. The resulting detonation pushes the piston into the pump tube. The piston's action heats and compresses the gas to thousands of pounds per square inch, which creates the driving force for the second stage.

In the second stage, a projectile is loaded into the launch tube. Once the first stage’s heat and pressure are high enough, a small steel rupture disk bursts, accelerating the projectile at up to about 18,000 miles per hour (about 10 times faster than a hunting rifle).

The target enters the Secondary Confinement Chamber (SCC), and passes through a free flight zone. The target then passes through the Ultrafast Closure Valve (UCV) and enters the Primary Target Chamber (PTC), which contains the impact of the projectile on the target. The impact of the projectile on the plutonium target drives the experiment.

The impact of the projectile on the target lasts roughly one-millionth of a second and can generate pressures of millions of times atmospheric pressure (80 million pounds per square inch) and temperatures of thousands of degrees.

The data gathered on the properties of plutonium and other actinides, under extremely high temperatures and pressures, allows us to improve our computer simulations and scientific theory while maintaining our nation’s nuclear deterrent.

Note: A video (JASPER Background UCRL-VIDEO-205712.m4v) is available that provides an overview of how the JASPER two-stage gas gun operates and is available upon request.

Figure 1: JASPER Gun Bay

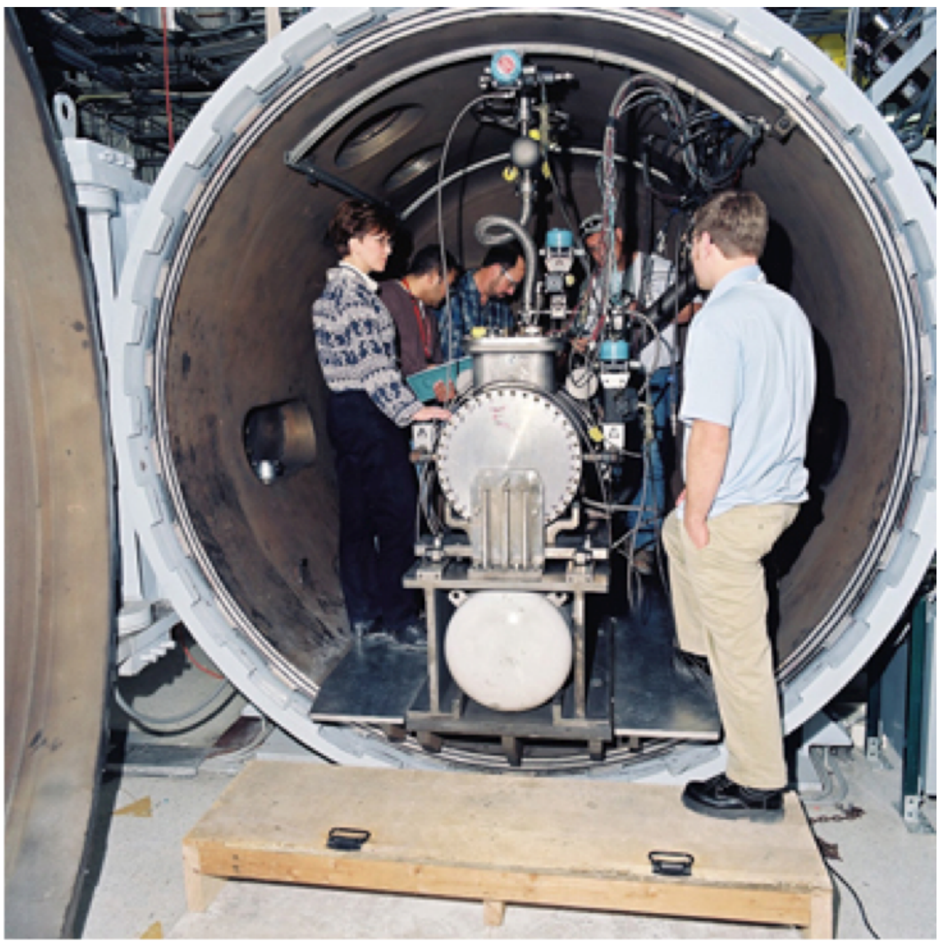


Figure 2: JASPER installing PTC into SCC

1.2 Executive Summary

The JASPER Facility's yearly schedule includes a two-month maintenance period and attempts to fire shots every three weeks during the rest of the year. A large amount of manpower, logistics, and cost, are associated with fabricating, assembling, delivering Target Assemblies and PTC Assemblies to maintain the shot rate. Unfortunately, if any contamination escapes from the PTC into the SCC, this contamination can shut the JASPER facility down for extended periods of time (no less than 6 months).

Contamination of the SCC has happened very infrequently, only twice, over the 14 year life of the JASPER facility. The latest incident has persuaded JASPER Management that it must mitigate and, if at all possible, prevent contamination to the SCC. It has been determined that corrosion of the plutonium target's surface is the source of this contamination. The PTC's gate valve and the Target Assembly's VAT valve must be opened to the atmosphere of the SCC just prior to the shot, so the projectile can impact the target's surface during the shot. When these isolation valves are opened and the atmospheres of the SCC, PTC, and Target Assembly equilibrate, there is the possibility for a small airflow to travel over the plutonium target's surface. This small airflow may lift and transport tiny corrosion particles into the SCC.

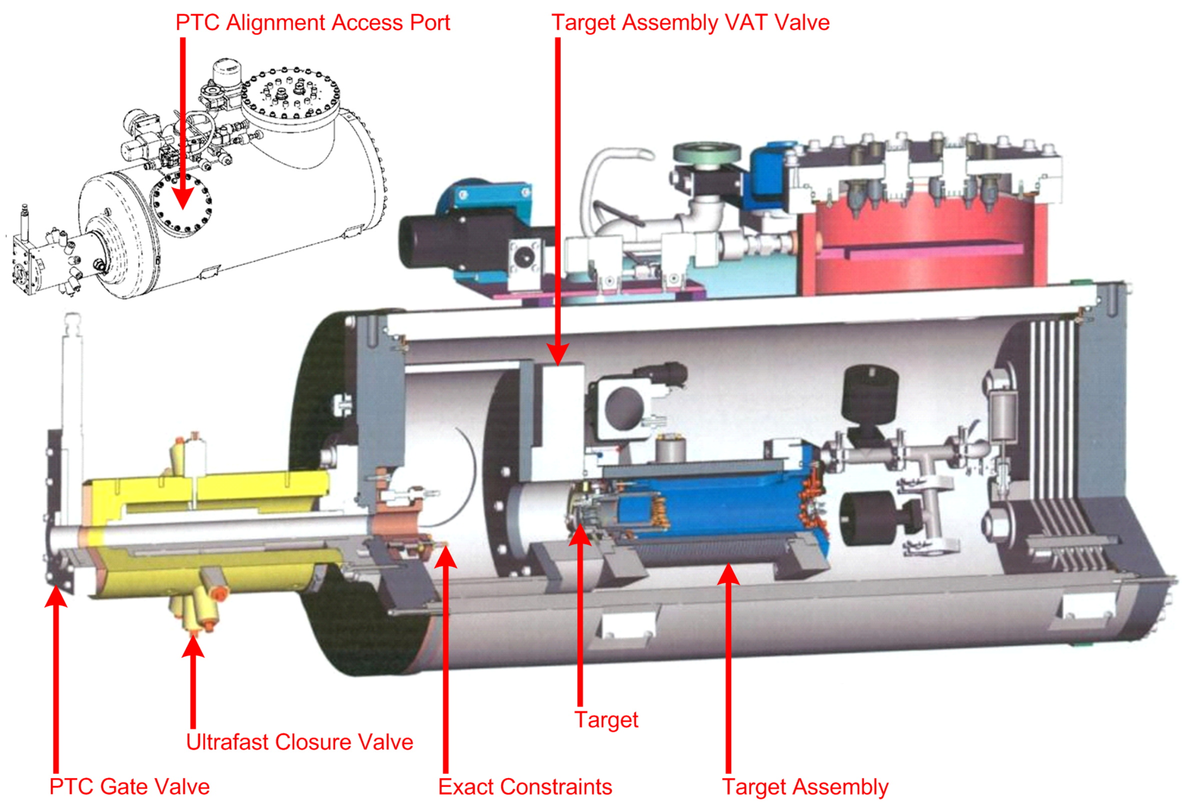


Figure 3: Primary Target Chamber (PTC) Assembly with and without Cutaway

Encapsulation of the plutonium target with epoxy has also been discussed, but is not applicable to all target designs, since it can interfere with projectile impact, shot data collection, and shot data quality.

Minimizing the storage time after final assembly will minimize the corrosion buildup on a plutonium target's surface and possibly prevent contamination. At assembly time a plutonium target is virtually corrosion free, but corrosion will buildup on the target's surface over time. In general, the time between assembly and use on a shot is as short as possible, but there are times when a PTC assembly must be stored (site or facility equipment failures, system maintenance, logistical holdups, management shutdowns, holidays, etc.). This mitigation manages the contamination source and works well, as long as the PTC assembly does not have to be stored for any extended period of time, and does not provide us with any information about the acceptability of the plutonium target in the PTC.

Minimizing the airflow that travels over the plutonium target surface will mitigate the spread of contamination. The following airflow minimization process was implemented at JASPER after the second contamination event. While setting up for a shot, the control system opens the PTC's Gate valve and the Target Assembly's VAT valve in the following steps:

1. Independently evacuate the SCC, PTC, and Target Assembly volumes and attempt to reach the same pressure in all three volumes using vacuum gages.
2. Open a valve in a HEPA filtered line between the SCC and PTC and equilibrate the combined volume.
3. Open the PTC Gate valve.
4. Independently evacuate the SCC/PTC and Target Assembly volumes and attempt to reach the same pressure in both volumes using vacuum gages.
5. Open a valve in a HEPA filtered line between the PTC and Target Assembly and equilibrate the combined volume.
6. Open the Target Assembly VAT valve.

Note: Our mechanical engineers and vacuum engineers cannot guarantee that this process will prevent contamination migration.

This mitigation does not manage the source of the contamination, and again it does not provide us with any information about the acceptability of the plutonium target in the PTC.

We propose a JASPER Target Corrosion Inspection (TCI) system that will evaluate a plutonium target's surface, and determine what changes have taken place to the target's surface since assembly. The TCI system would inspect the surface of a plutonium target just after assembly, just before use on a shot, and analyze the surface changes. This information will be presented to the JASPER Operators, Scientists, and Management, who can then make a determination of the target's acceptability. We propose two sets of data: standard images with a calibration marker, in view, to evaluate visible changes to surface; and light scatter images to evaluate changes to surface roughness.

The JASPER Facility Management, Scientists, and Operators, as a "sacred goal", want a system that will minimize and, if possible, prevent contamination to the SCC. The JASPER TCI system will allow JASPER Operators to evaluate the corrosion status of a plutonium target installed in a

PTC, before the PTC is used on a JASPER shot. We believe the JASPER TCI system will tackle the source of the contamination and meet all of the users' needs.

2.0 Mission Description

The JASPER Target Corrosion Inspection (TCI) system mission is to determine the level of corrosion that accumulates on a JASPER plutonium target, and provide information to the users that indicate if the level of corrosion makes it unacceptable for use on a JASPER shot.

The following is a very simplified explanation of plutonium oxide corrosion. Other corrosion processes exist that are based on other gases and surface contamination (water, oil, etc.), but oxidation in air is the predominant process. Plutonium looks like nickel when freshly machined or polished; when it is initially exposed to air (20% oxygen) it creates an initial layer of plutonium oxide, PuO_2, which looks like tarnished metal. As the plutonium oxide layer slowly grows, oxygen continues to diffuse through the initial layer to a typical depth of 4-5µm (J.M. Haschke et al. 2000). Once the oxygen has diffused to this depth, the internal stresses on the material cause spallation to occur and very fine particles break away from the surface at sizes of 4-5µm. These very fine particles form plutonium oxide powder, PuO_2. This plutonium oxide powder is dangerous, because it may become airborne and inhaled into the lungs. This powder is the primary contamination that we are trying to mitigate. The plutonium oxide tarnish and corrosion may vary in color: yellow, grey, green, olive, or black. Moist or humid air rapidly increases the oxidation rate.

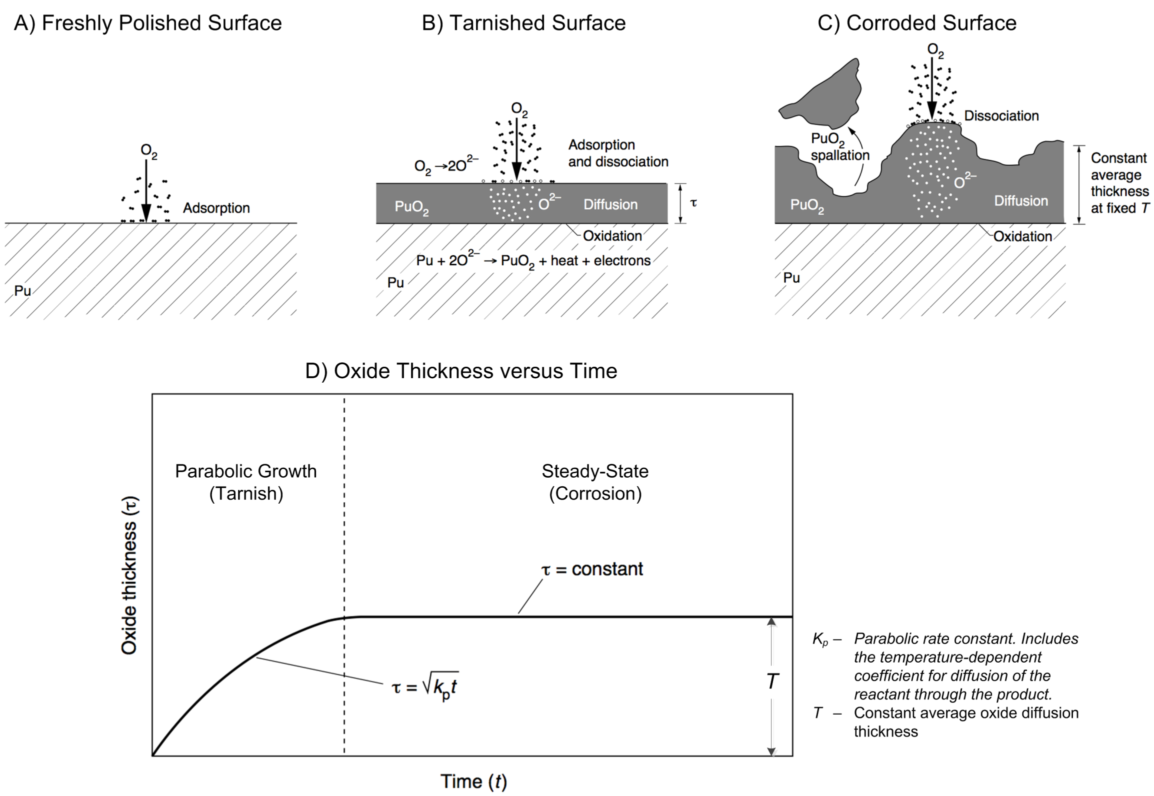


Figure 4: Plutonium Corrosion Process (J.M. Haschke et al. 2000)

The TCI system proposes two imagers that will collect image data on a given plutonium target at assembly time and prior to use on a shot.

The first, is a standard camera that can capture images and be used to determine if the target's surface color and finish has changed. The use of a calibration marker provides a standard that allows images taken at different times to be processed and adjusted to correct for lighting differences. At assembly, the target's surface is nickel in color and polished to a reflective metallic finish, with a surface roughness of approximately 0.1µm. When inspecting the target for changes, the surface color may change and the surface finish may change:

- If the color has not changed measurably and the surface finish is still metallic, then there is a high probability that corrosion spallation has NOT occurred on the surface of the plutonium target, making it acceptable for use.
- If the color has changed measurably and the surface finish is still reflective, then there is a high probability that tarnishing has occurred, but corrosion spallation has NOT occurred on the surface of the plutonium target. This case will be a learning process where we will have to look at the scatter data and determine if we can see measureable differences in the surface roughness as the tarnish progresses to corrosion spallation.
- If the color has changed measurably and the surface finish is completely matte, then there is a high probability that corrosion spallation has occurred and very fine particles have formed on the surface of the plutonium target, making it unacceptable for use.

The second, is an imager that can capture light scatter that can be used to determine the target's surface roughness. If we can determine that the plutonium target's surface roughness is less than 4-5µm then we can safely say that there is a high probability that corrosion spallation has NOT occurred and very fine particles have NOT formed on the surface of the plutonium target, making it acceptable for use.

There are a number of risks involved and we will have to learn how well both of these options will perform. The expectation is that it will be better than what has been done in the past, which was nothing.

2.1 Active Stakeholders

This section lists and describes the active stakeholders that directly influence the TCI system and outlines their expectations. The active and passive stakeholders for the TCI system are also identified in the context diagram shown in figure 5.

2.1.1 JASPER Operators

Operators are responsible for the JASPER facility's experimental systems. The operators configure the auxiliary systems and diagnostic systems and guide the JASPER facility through the various states required to perform an experiment. The operators are subject matter experts, with years of experience. Operators use their knowledge of these systems and the status they provide, to determine if the systems are performing properly at each state of the experiment. The operators' expectations are:

Item	Expectation	Why?
1	The TCI system must provide a clear indication of the plutonium target's operational acceptability.	That is the job that it needs to perform.
2	The TCI system must be safe to operate.	All electrical hazards and eye hazards (lasers) must be identified and managed.
3	The TCI system must be easy to setup and operate.	So that operators like myself can use it.

2.1.2 JASPER Principle Investigator

The principle investigator is responsible for planning and ensuring the JASPER facility is prepared to collect high quality data for the experiment. On shot day, the experimental lead verifies all operators believe that the systems that they are responsible for are setup for the experiment, ready to perform their tasks at each state of the shot, and that each gun performance and shot diagnostic collects high quality data. The principle investigator's expectations are:

Item	Expectation	Why?
1	The TCI system must eliminate or minimize Plutonium contamination (in the SCC).	That is the most important function.
2	The TCI system must maximize the quality of physics data.	Any level of Plutonium corrosion on the target can reduce data quality.

2.1.3 JASPER Electronics Lead

The electronics lead is responsible for the JASPER facility electronic control systems. The electronics lead directs the electronic engineers and electronic technicians that design, develop, fabricate, install, and upgrade all JASPER electronic control systems. The electronics lead is also responsible for testing these systems after installation and after each upgrade, to validate them before they are turned over to the facility operations team. The electronics lead's expectations are:

Item	Expectation	Why?
1	The TCI system must mitigate Plutonium contamination in the SCC.	That is the primary function.
2	The TCI system must, within reason, use commercial-off-the-shelf (COTS) electronic components.	So that maintenance costs are minimized.
3	The TCI system must, where possible, use standard JASPER systems and tools, such as computers (PCs), programmable logic controllers (PLCs), scopes, programming languages, etc.	So that the controls team can use the same tools they currently use to develop the control system.

2.1.4 JASPER Mechanical Lead

The mechanical lead is responsible for the JASPER facility mechanical systems. The mechanical lead directs the mechanical engineers and mechanical technicians that design, develop, fabricate, install, and upgrade all JASPER mechanical systems. The mechanical lead is also responsible for testing these systems after installation and each upgrade, to validate them before they are turned over to the facility operations team. The mechanical lead's expectations are:

Item	Expectation	Why?
1	The TCI system must measure the level of Plutonium corrosion on the target's surface. A corrosion thickness of >5µm is considered a contamination issue.	It will mitigate contamination.
2	The TCI system must measure the level of Plutonium corrosion on the target's surface. A corrosion thickness of >2.5µm is considered a physics measurement issue.	It will improve physics data quality.
3	The TCI system must view the target through the sapphire window in the Target Assembly VAT valve.	That is the only viewport to the target.
4	The TCI system must be able to mount to the Target Assembly and function, prior to the Target Assembly being assembled in the PTC.	Initial assembly data is best taken in this configuration.
5	The TCI system must be able to mount to the PTC assembly and function, after the Target Assembly has been assembled in the PTC.	After PTC assembly and prior to a shot, data can only be taken in this configuration.
6	The TCI system must have a mechanical mount point that provides repeatable results. *Note: Expectations 4 and 5 above will complicate implementation of this expectation.*	Alignment and image results must be repeatable.
7	The TCI system must be able to fit through the PTC's Alignment Access Port, after the Target Assembly has been assembled into the PTC.	This port provides the best access to the Target Assembly VAT valve's sapphire window.

2.1.5 JASPER Physics Lead

The physics lead is responsible for developing the plutonium targets used on JASPER shots. The physics lead manages the physics team that develops shot requirements, designs, and diagnostics. The physics lead then directs the mechanical lead, electrical lead, and principle investigator to go forth and implement the physics team's plans. The physics lead's expectations are:

Item	Expectation	Why?
1	The TCI system must provide a go or no-go decision on contamination.	This is the system's primary task.
2	The TCI system must provide a go or no-go decision on the risk to physics data.	This is the system's secondary task.

Item	Expectation	Why?
3	The TCI system must provide a light scatter image of the plutonium target at assembly time and prior to use on a shot, so that a numerical comparison can be made.	The light scatter image of the target's surface is the easiest way to determine that a measureable change has occurred.

2.1.6 JASPER Program Lead

The program lead is responsible for the JASPER program and holds the purse strings for all JASPER program tasks. The program lead works closely with the physics lead, mechanical lead, electronics lead, and principle investigator, making sure all programmatic plans are implemented according to plan, schedule, and budget. The JASPER program lead is responsible for making sure that the JASPER program and the JASPER facility comply with all applicable government regulations. The program lead's expectations are:

Item	Expectation	Why?
1	The TCI system must keep the SCC contamination free.	Because I don't want the SCC contaminated again.
2	The TCI system must provide a picture of the plutonium target at assembly time and prior to use on a shot, so that a visual comparison can be made.	A picture of the target's surface is the best way to convey the changes to the target's surface to management and observers.

2.2 Passive Stakeholders

This section lists and describes the passive stakeholders that indirectly influence the TCI system and outlines their expectations.

2.2.1 All Other JASPER Personnel

When the JASPER SCC was contaminated with Plutonium dust, all facility and program personnel were affected by the event. The facility was shut down while a hazardous materials team evaluated the situation, attempted to ascertain the level of contamination, determined if the SCC could be cleaned up, or if the entire vessel needed to be hauled away as hazardous waste. This affected everyone's current assignment and careers. It affected the JASPER program's schedule, budget, and scope. In general, when asked, the JASPER personnel don't want this type of event to ever happen again.

2.2.2 LLNL Management

The JASPER program is under the direction of LLNL Management. LLNL Management is responsible for providing an advertised capability for a reasonable cost. The ability to provide high quality plutonium "equation-of-state" data that can improve our computer simulations is an important capability. LLNL Management needs that data along with improved computer simulations, so that they can assure the US Government that our nation's stockpile is functional, without having to field-test it. Plutonium contamination events are costly and embarrassing for LLNL Management. LLNL Management knows that events can happen, and makes plans for their eventuality, but they would rather have a facility that operates smoothly, without any events.

2.2.3 US Government

The JASPER facility and program are paid for and operated by taxpayer funding that is provided by the US Government. The experiments provide value to the US Government, the Department of Energy (DOE), and the Department of Defense (DOD). The "equation-of-state" data collected on plutonium at JASPER allows us to improve our computer simulations and scientific theory, while maintaining our nation's nuclear deterrent. Plutonium contamination events are costly and embarrassing for the US Government, and in general, are considered unacceptable events by the US Government.

2.2.4 US Citizens

The JASPER facility and program are ultimately paid for by US Citizens, a.k.a. taxpayers. The data gathered by the JASPER facility is used to provide for the safety and security of all US Citizens. They benefit from having reliable systems that provide high quality data, at a reasonable cost, but ultimately these systems are expected to operate safely.

2.2.5 Plutonium Target

The plutonium target is a stakeholder for this system. The plutonium corrosion process is complicated. Not much information exists on the changes to the surface while the material transitions from the initial tarnishing state to the corrosion spallation state. This means we will have to go through a discovery process to understand the results presented by the TCI system.

2.2.6 Mechanical Environment (TA & PTC vessels)

The mechanical environment that the plutonium target is currently housed in, the Target Assembly vessel and the PTC vessel, generate environmental constraints to the design of the TCI system. The sapphire window in the Target Assembly VAT valve is the only view port we can look through to see the plutonium target. The PTC's alignment access port is the best access path to the face of the Target Assembly VAT valve. The Target Assembly and PTC both provide possible mounting locations that will help The TCI system generate repeatable results.

2.3 Sacred Expectations

Initially, there were two candidates for the list of sacred expectations. Besides the sacred expectation that all of the active stakeholders identified, a possible second sacred expectation was: "The TCI system must maximize the quality of physics data". This was dropped when the JASPER Program Lead made it clear that mitigating plutonium contamination was our only sacred goal. If in meeting our “sacred goal” we also happen to maximize our physics data quality, then it's a bonus.

Item	Sacred Expectation	Why?
1	The TCI system must mitigate Plutonium contamination from migrating into the SCC.	This is the primary basis for the TCI systems existence.

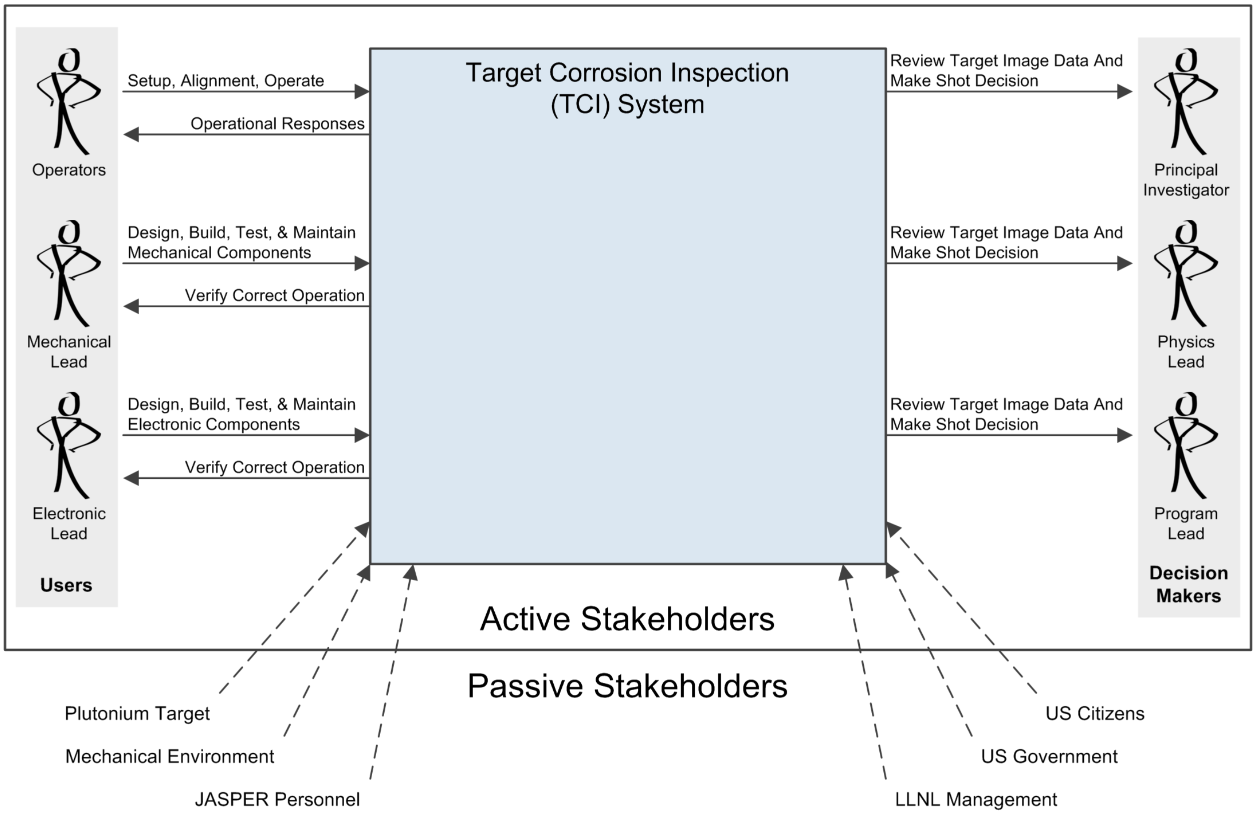


Figure 5: Context Diagram

3.0 System Operational Context and Reference Operational Architecture

Since the TCI system is new to the JASPER facility, there is no legacy implementation to compare it to. The JASPER facility has never had the capability that the TCI system is envisioned to provide.

3.1 System Operational Context

The TCI system has no legacy implementation to use as a basis for a System Operational Context.

3.1.1 Users

The primary Users of the TCI system will be the operators, mechanical lead, and electrical lead. During design, implementation, and testing, the TCI system's primary Users will be the mechanical lead and electrical lead, with help from the operators. After the TCI system has been turned over to the JASPER operations team, the TCI system's primary Users will be the operators, with help from the mechanical lead and the electrical lead.

The Mechanical Lead will direct a team that will design, implement, test, and maintain the TCI system's mechanical design. The TCI system's mechanical design has to house the imaging components: standard imager, standard flash (light source), light-scatter imager, and light-scatter flash (light source). The mechanical design must also provide a mounting fixture that will allow for repeatable results.

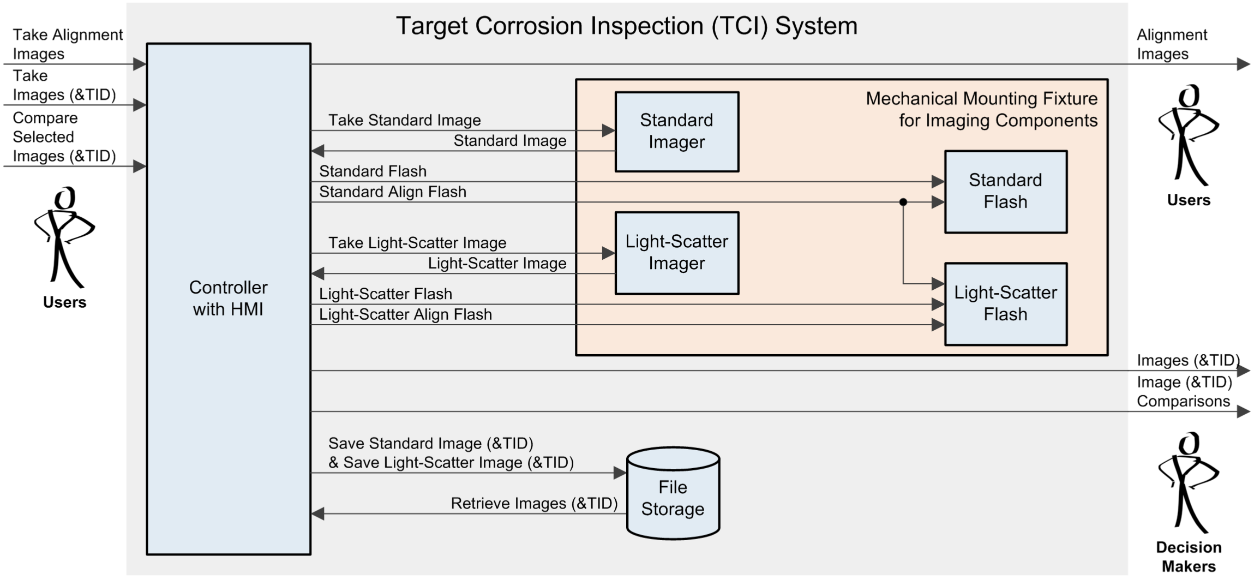
The Electronic Lead will direct a team that will design, implement, test and maintain the TCI system's electrical design. The TCI system's electrical design includes the imaging components: standard imager, standard flash (light source), light-scatter imager, and light-scatter flash (light source). The electrical design also includes a control system made up of a controller, human machine interface (HMI), and file storage; which will be used to control the imaging components.

The Operators will setup, align, and operate the TCI system. The Operators will be instrumental in helping the Mechanical Lead design the alignment mechanism, and also in helping the Electrical Lead design the HMI.

3.1.2 Decision Makers

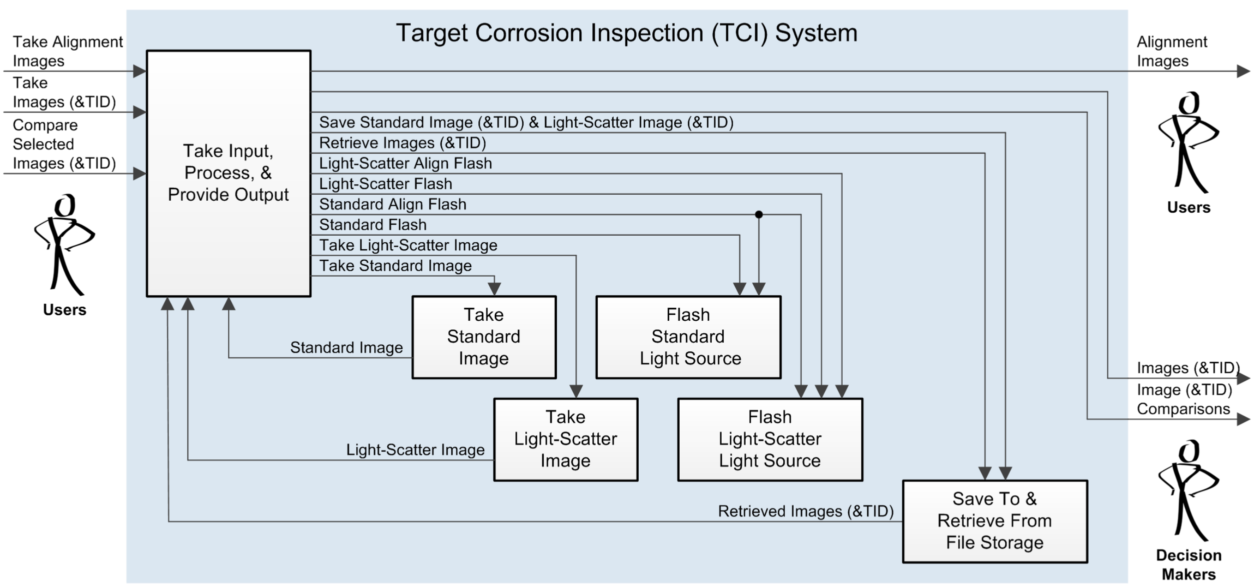
The primary Decision Makers of the TCI system will be the principle investigator, physics lead, and program lead. During design, implementation, and testing, the TCI system's Decision Makers will be watching the budget, schedule, and compliance. After the TCI system has been turned over to the JASPER operations team, the TCI system's Decision Makers will be anxiously waiting for the plutonium target image data and image comparison analysis.

3.2 Reference Operational Architecture



Note:
Users - *Operators, Electronic Lead, Mechanical Lead*
Decision Makers - *Principle Investigator, Physics Lead, Program Lead*
TID - *Target Identifier*

Figure 6: Physical Architecture Diagram



Note:
Users - *Operators, Electronic Lead, Mechanical Lead*
Decision Makers - *Principle Investigator, Physics Lead, Program Lead*
TID - *Target Identifier*

Figure 7: Functional Architecture Diagram

The TCI system has no legacy implementation to use as a basis for a Reference Operational Architecture. The TCI system is made up of mechanical and electrical components, each performing a specific function. The TCI system's components are identified in a physical architecture diagram in figure 6, a functional architecture diagram in figure 7, and are also described in the following sections:

3.2.1 Mechanical Mounting Fixture

The mechanical mounting fixture houses the TCI system's imaging components: standard imager, standard flash, light-scatter imager, and light-scatter flash. The mechanical mounting fixture provides the User with the ability to manually align the imaging components onto the plutonium target located inside the Target Assembly, which may also be located inside the PTC assembly.

The Mechanical Mounting Fixture is shown in the physical architecture diagram in figure 6, but is missing from the functional architecture diagram in figure 7. There are two reasons for not identifying the functionality of the Mechanical Mounting Fixture at this time:

- The Electrical Lead knows that there are many possible configurations for the imaging components. The configurations depend on the imaging components that are lab tested and finally determined to work. Since different configurations will have different alignment requirements, the alignment functionality is left to-be-determined (TBD).
- The Mechanical Lead believes that there is the possibility that the alignment process may not be necessary. To get repeatable results the TCI imaging components and the plutonium target must have consistent locations with respect to each other. The TCI imaging components must be located in the same location and orientation, in both the Target Assembly and PTC configurations. The plutonium target must be located in the same location and orientation, inside the Target Assembly.

3.2.2 Controller

The controller is the TCI system's processer that takes input commands from the HMI, processes the commands using the imaging components (standard imager, standard flash, light-scatter imager, and light-scatter flash), and returns responses and results back to the HMI. The controller provides the User with the following functions: Take Alignment Images, Take Images (&TID), and Compare Selected Images (&TID). Each of these commands uses the term "images" which means an image pair (standard image and light-scatter image). The (&TID) associated with a command means, the User must enter the plutonium target's unique Target Identifier (TID), so that the controller can associate it with each image pair.

3.2.3 Human Machine Interface (HMI)

The HMI is the TCI system's interface to the User. The HMI takes command input from the User and communicates it to the controller so that it can perform the requested command function. The controller communicates the command responses and results back to the HMI for output to the User.

3.2.4 File Storage

The File Storage is the TCI system's data repository for image pairs taken (standard and light-scatter). When the controller performs the Take Images (&TID) command, it saves the files of the image pair with that unique Target Identifier (TID) to the file storage. When the controller performs the Compare Selected Images (&TID) command, it retrieves all image pairs associated with that unique TID and presents them to the User for selection and comparative analysis.

3.2.5 Imaging Components

3.2.5.1 Standard Imager

The standard imager is the TCI system's device used to take a standard image of the plutonium target normally with the standard flash as a light source. When taking alignment images the standard imager needs both the standard flash and the light-scatter flash so that the User can verify the light-scatter flash is on target.

3.2.5.2 Standard Flash

The standard flash is the TCI system's device used to provide a light source for the standard imager.

3.2.5.3 Light-Scatter Imager

The light-scatter imager is the TCI system's device used to take a light-scatter image of the plutonium target with the light-scatter flash as a light source.

3.2.5.4 Light-Scatter Flash

The light-scatter flash is the TCI system's device used to normally provide a light source for the light-scatter imager. When taking alignment images, the light-scatter flash is also flashed when taking the standard image so that the User can verify the light-scatter flash is on target.

4.0 System Drivers and Constraints

4.1 System Drivers

4.1.1 Plutonium Contamination to the SCC - Primary

The primary TCI system driver is that JASPER Management made a decision that it must mitigate contamination to the SCC. It has been determined that corrosion of the plutonium target's surface is the source of this contamination.

4.1.2 TCI System Costs

The cost of the TCI system including mechanical design, electrical design, components, fabrication, and testing is much less than the cost of either of the previous incidents that occurred. So, in this respect, cost is not a major system driver, although it is a factor.

4.2 Constraints

4.2.1 Physical Constraints

4.2.1.1 Target Assembly Configuration

The TCI system must be able to mount to the Target Assembly and function, prior to the Target Assembly being assembled into the PTC.

4.2.1.2 PTC Configuration

The TCI system must be able to mount to the PTC assembly and function, after the Target Assembly has been assembled into the PTC.

4.2.1.3 Target Assembly and PTC - Mounting

There are three options for mounting the TCI system:

1. The PTC's Alignment Access Port may provide a mounting location for the TCI system, which is only available in the PTC configuration.
2. The PTC's Exact Constraints may provide a mounting location for the TCI system, which is only available in the PTC configuration.
3. The Target Assembly's VAT valve port may provide a mounting location for the TCI system, which is available in both the Target Assembly configuration and PTC configuration. Since this location is available in both configurations, it may also provide the best functional repeatability and minimize alignment time.

4.2.1.4 Target Assembly - VAT Valve Sapphire Window

The sapphire window in the Target Assembly's VAT valve provides the only view of the plutonium target's surface. The sapphire window will affect the light that is transmitted to and reflected from the plutonium target's surface, including the light transmitted by the TCI system's light sources and the light received by the TCI system's imagers.

4.2.1.5 Target Assembly - Plutonium Target

The plutonium target is located inside the Target Assembly. The plutonium target's mount location consistency and mount stability will affect the TCI system's alignment repeatability.

4.2.1.6 PTC - Alignment Access Port

The PTC's alignment access port will provide the TCI system's only access to the Target Assembly's VAT valve sapphire window, when the Target Assembly is mounted in the PTC. This will limit the size of the TCI system's mechanical fixtures, cameras, and flash light sources.

4.2.2 Operational Constraints

4.2.2.1 Access Time for Pre-Shot Inspection

The time required for a User to: access the PTC, install the TCI system, perform alignment using Take Alignment Images command, take current images of the plutonium target using the Take Images (&TID) command, and Remove the TCI system from the PTC, will be limited to one hour. This will minimize interference with the JASPER personnel who are busy preparing for a shot. The operators believe the actual access time to be consistent with the allotment, but this will depend on the complexity of performing alignment.

4.2.2.2 Analysis Time for Pre-Shot Inspection

After the TCI system is removed from the PTC, the time required for a User to perform analysis using Compare Selected Images (&TID) command will be limited to four hours. The Decision Makers would like four hours so that they can make the decision on the same day (the night before the shot). The electronic lead believes the actual analysis time should be short, on the order of seconds, and the allotment of time given to be extremely generous.

5.0 Operational Scenarios

The TCI system will provide three operational scenarios for the Users to request through the HMI: Take Alignment Images, Take Images (&TID), and Compare Selected Images (&TID). These operational scenarios are generally used sequentially and will generally constitute a target inspection.

5.1 Take Alignment Images

The User has to align the TCI system to the target. The TCI system's mechanical mounting fixture provides a manual method of adjusting the alignment. Using the TCI system's HMI, the User selects the Take Alignment Images command, and The TCI system will take alignment images and present them to the User. The TCI system will take two alignment images: the first alignment image uses the standard imager and both the standard flash and light scatter flash; the second alignment image uses the light-scatter imager and the light-scatter flash. The User may run the Take Alignment Images command in a "continuous-loop", until the manual alignment process is complete. When the manual alignment process is complete, the TCI system's imagers and their light sources are properly aligned. The approximate functional sequence for the Take Alignment Images command is shown in the sequence diagram in figure 8 and mapped out in the functional architecture diagram of figure 9.

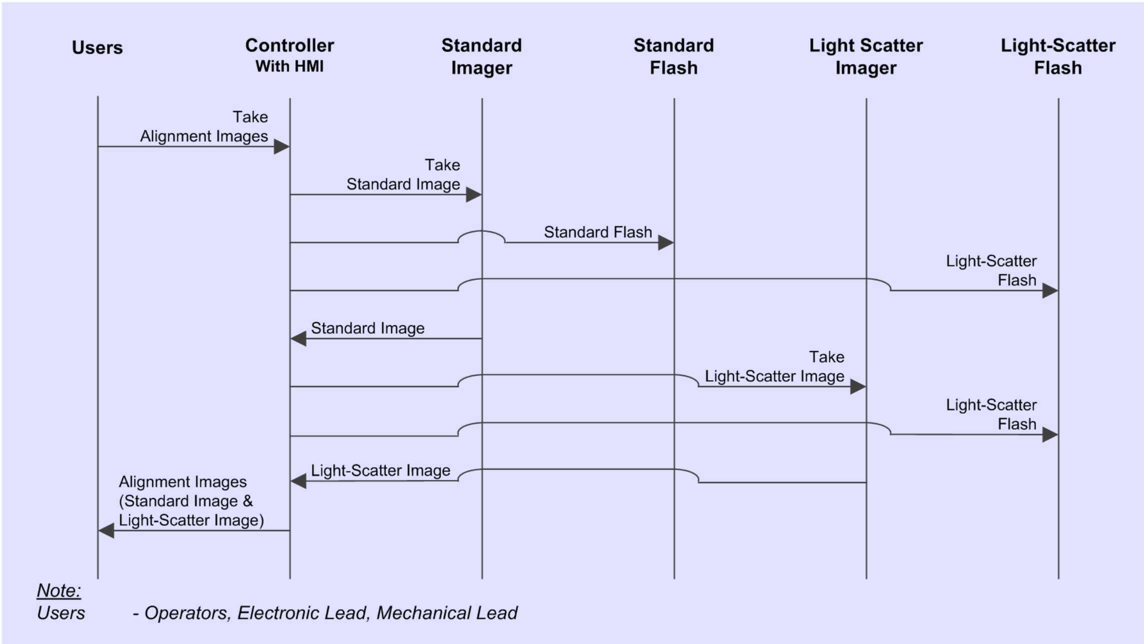
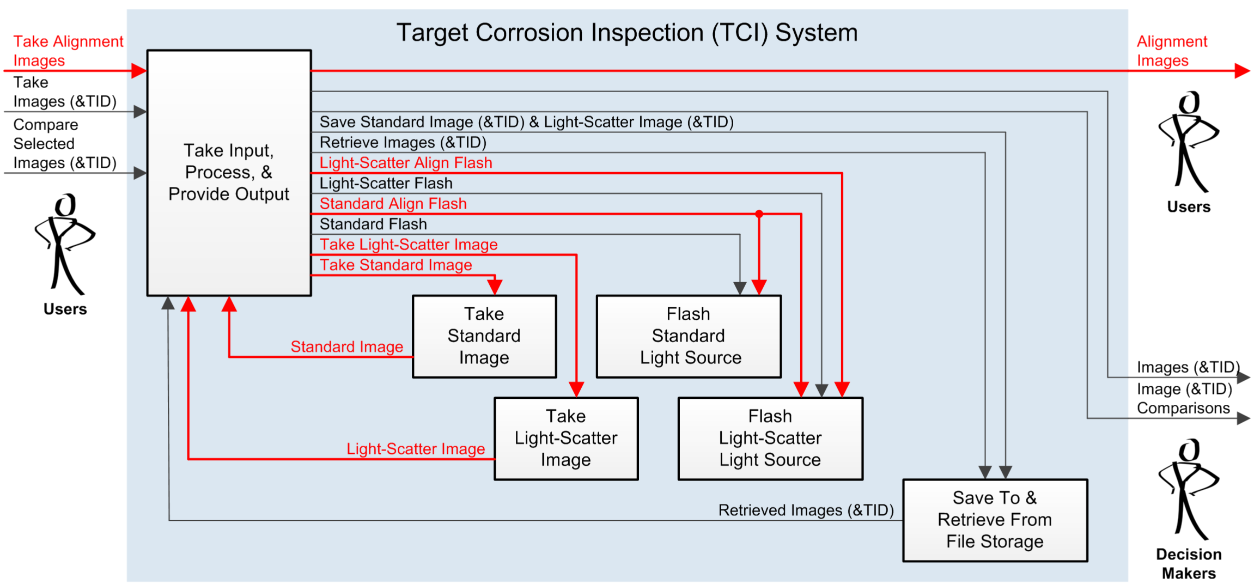


Figure 8: Sequence Diagram: Use Case - Take Alignment Images



Note:
Users - *Operators, Electronic Lead, Mechanical Lead*
Decision Makers - *Principle Investigator, Physics Lead, Program Lead*
TID - *Target Identifier*

Figure 9: Functional Architecture Diagram: Use Case - Take Alignment Images

5.2 Take Images (&TID)

Once the TCI system is aligned, the User is then ready to take the images of the plutonium target. Each plutonium target has a unique Target Identifier (TID) that the TCI system associates with each image pair it takes. Using the TCI system's HMI, the User selects the Take Images (&TID) command, enters the TID, and the TCI system will take an image pair (a standard image and a light-scatter image), which will be time-stamped and saved to file storage, as well as presented to the User. The User will turn over the image pair taken to the Decision Makers. The approximate functional sequence for the Take Images (&TID) command is shown in the sequence diagram in figure 10 and mapped out in the functional architecture diagram of figure 11.

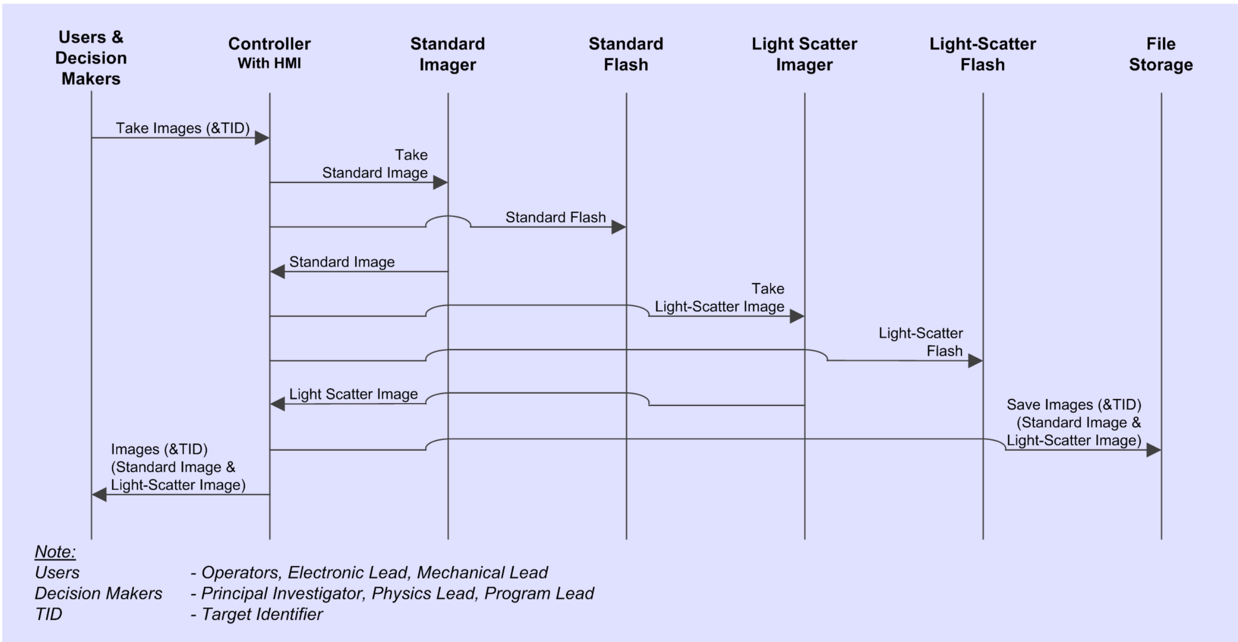
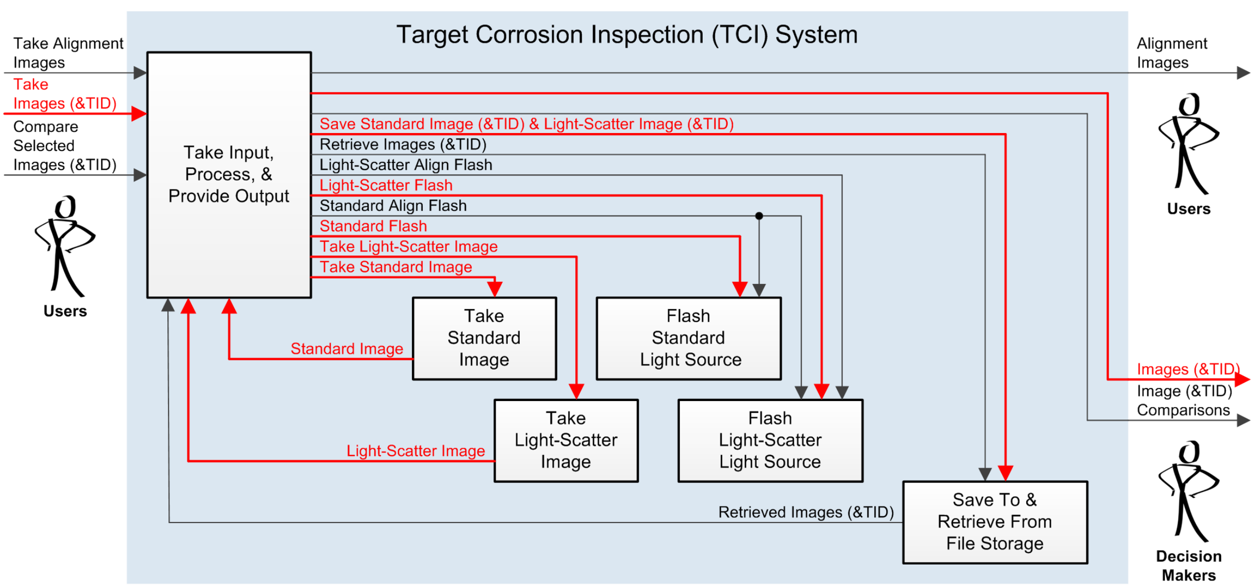


Figure 10: Sequence Diagram: Use Case - Take Images (&TID)



Note:
Users - *Operators, Electronic Lead, Mechanical Lead*
Decision Makers - *Principle Investigator, Physics Lead, Program Lead*
TID - *Target Identifier*

Figure 11: Functional Architecture Diagram: Use Case - Take Images (&TID)

5.3 Compare Selected Images (&TID)

Once the TCI system has taken the latest images, the User is then ready to compare selected images. Each plutonium target has a unique Target Identifier (TID) that the TCI system associates with each image pair it takes. Using the TCI system's HMI, the User selects the Compare Selected Images (&TID) command, enters the TID, and the TCI system provides a list of all image pairs (a standard image and a light-scatter image) associated with that TID in time stamp order. The User then selects two image pairs to compare, usually the initial and current image pairs. Once selected, the TCI system will compare those image pairs and provide analysis to the User. The User will turn over the images and analysis to the Decision Makers. The approximate functional sequence for the Compare Selected Images (&TID) command is shown in the sequence diagram in figure 12 and mapped out in the functional architecture diagram of figure 13.

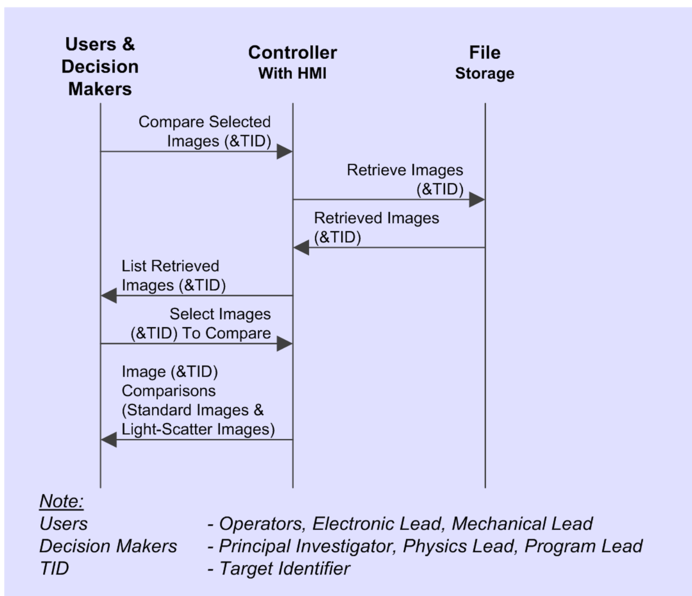


Figure 12: Sequence Diagram: Use Case - Compare Selected Images (&TID)

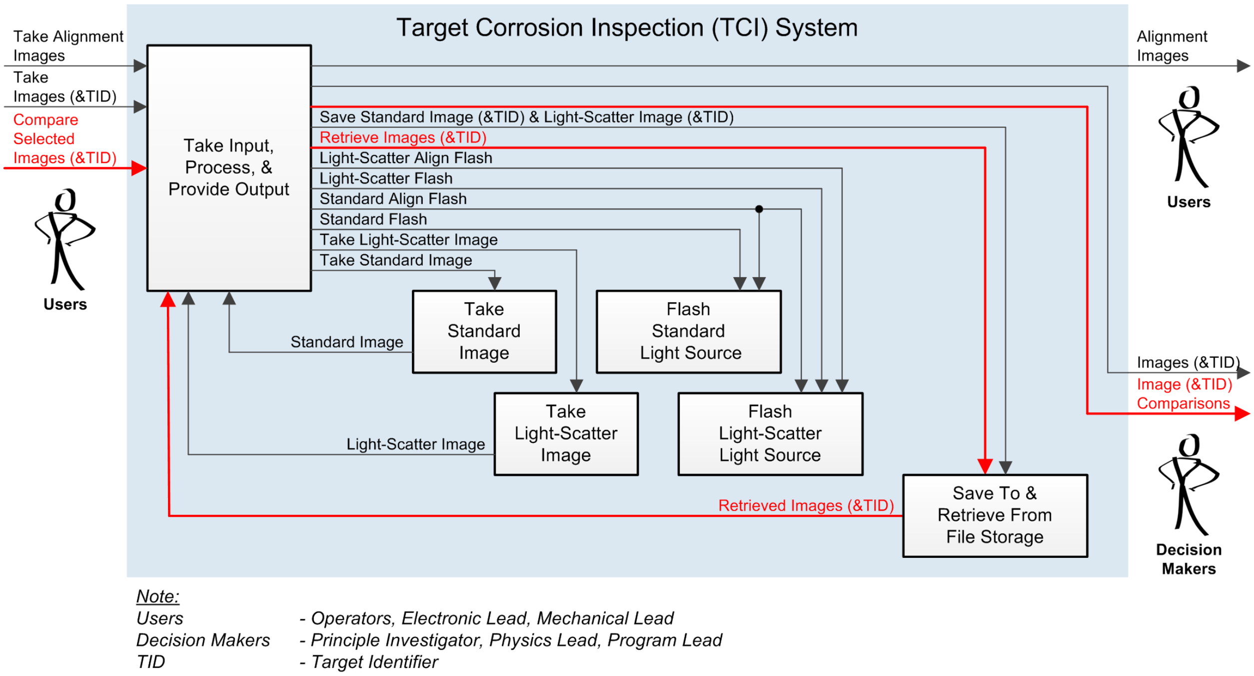


Figure 13: Functional Architecture Diagram: Use Case - Compare Selected Images (&TID)

5.4 Integration of TCI System into JASPER Operations

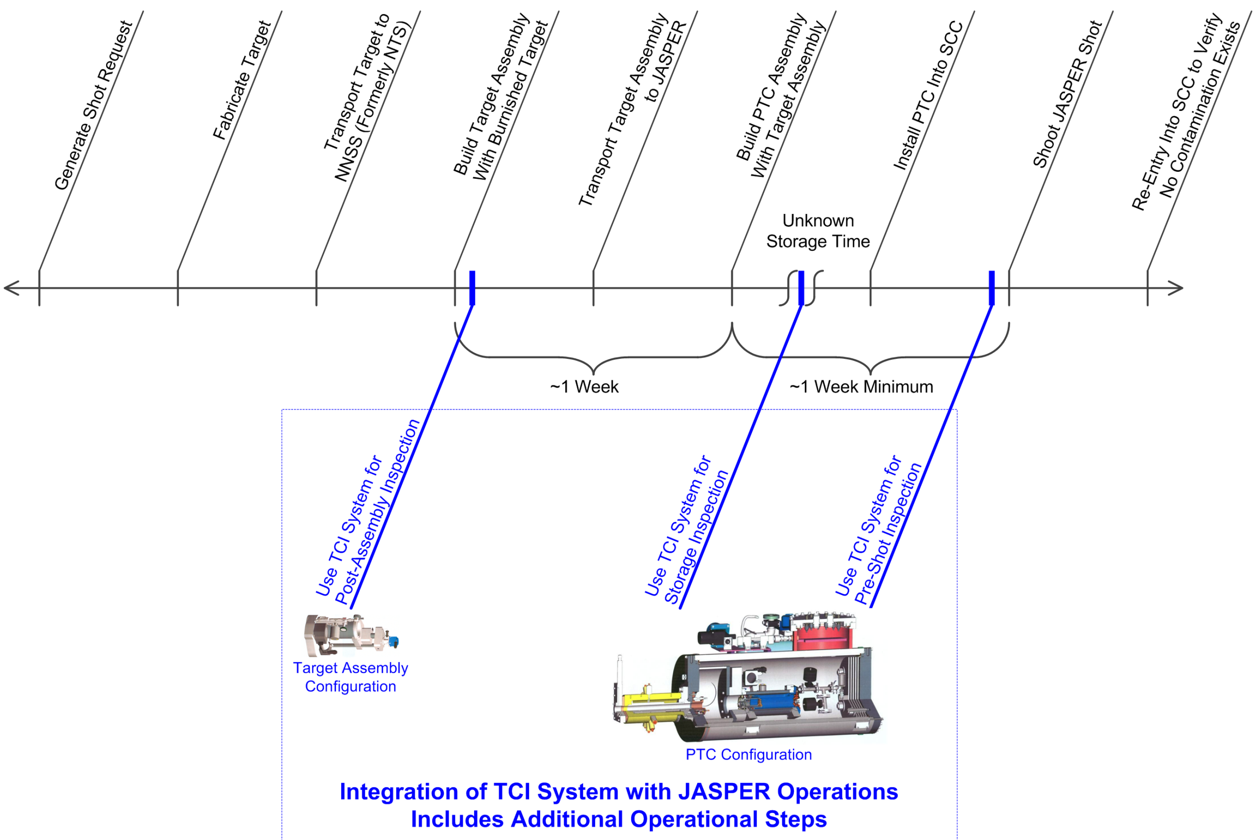


Figure 14: Integrating TCI System into JASPER Operations Timeline

The initial plan for integrating the TCI system into JASPER operations is to add the following steps into the JASPER operations timeline, also shown in figure 14:

5.4.1 Initial Post-Assembly Inspection

This inspection will take place immediately after the building of the Target Assembly. The plutonium target's surface is freshly polished, which provides the best time to take baseline data. The TCI system will have to be used in the Target Assembly configuration, since the Target Assembly will not be installed into a PTC until it is transported to the JASPER facility.

The User will have to install the TCI system on the Target Assembly and verify alignment, using the Take Alignment Images command. Once aligned, the User will then take the first images of the plutonium target using the Take Images (&TID) command. The user will NOT be able to use the Compare Selected Images (&TID) command since there is only one time-stamped image pair for the target, and a second is necessary to make comparisons.

5.4.2 Storage Inspection

This inspection will take place sometime after the building of the PTC Assembly and the PTC has been in storage, for some currently unknown operational or programmatic reason. The TCI system will have to be used in the PTC configuration.

The User will have to install the TCI system inside the PTC and verify alignment using the Take Alignment Images command. Once aligned, the User will then take the current images of the plutonium target using the Take Images (&TID) command, then make comparisons of the current images with the first images, taken at assembly, using the Compare Selected Images (&TID) command.

The plutonium target's surface will have some level of oxidation. The TCI system should provide the Decision Makers with the information necessary to, either leave the PTC in storage, or disassemble it and send the Target Assembly back for refurbishment.

5.4.3 Pre-Shot Inspection

This inspection will take place sometime after the PTC has been installed into the SCC and prior to final shot preparation. The TCI system will have to be used in the PTC configuration.

The User will have to install the TCI system inside the PTC and verify alignment using the Take Alignment Images command. Once aligned, the User will then take the current images of the plutonium target using the Take Images (&TID) command, then make comparisons of the current images with the first images, taken at assembly, using the Compare Selected Images (&TID) command.

The plutonium target's surface will have some level of oxidation. The TCI system should provide the Decision Makers with the information necessary to, either go forward with the

JASPER shot, or scrub the shot (i.e., disassemble and send the Target Assembly back for refurbishment).

The expectation is that we will have to use the TCI system over a period of time, with various targets, evaluating the images and analysis provided, before we gain enough experience in its proper utilization.

5.4.3.1 Pre-Shot Timeliness

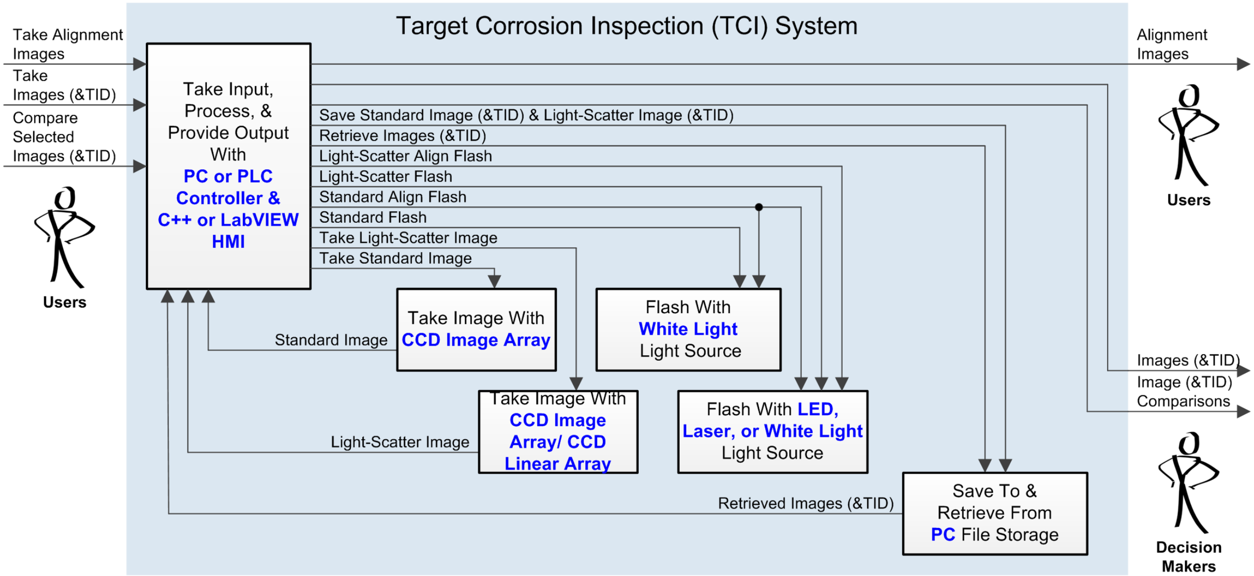
Once the PTC is installed into the SCC the major timeliness issues associated with the TCI system are operational constraints:

- "Access Time for a Pre-Shot Inspection" is limited to one hour, to minimize interference with JASPER personnel who are busy preparing for a shot.
- "Analysis Time for a Pre-Shot Inspection" is limited to four hours, so that the decision makers can make a timely decision to either go forward with the shot or scrub it.

6.0 Implementation Concepts Selected And Rationale

The component options for the TCI system are based on user experience with similar components used in developing many diagnostics for LLNL's various experimental facilities, and are identified in figure 15. Each component will be graded with either a positive "+", negative "-", or satisfactory "S", for each criteria item. The criteria used to evaluate these components was taken from the TCI system's stakeholders' expectations:

Item	Criteria	Basis
1	Evaluate Level of Corrosion	Sacred Expectation from all Stakeholders
2	Safety Concerns	Expectation #2 from the Operators
3	Ease of Use	Expectation #3 from the Operators
4	COTS Component	Expectation #2 from the Electrical Lead
5	JASPER Standard	Expectation #3 from the Electrical Lead
6	Component Size	Expectation #7 from the Mechanical Lead



Note:
Users - *Operators, Electronic Lead, Mechanical Lead*
Decision Makers - *Principle Investigator, Physics Lead, Program Lead*
TID - *Target Identifier*

Figure 15: Functional Architecture Diagram with Options

6.1 Component Evaluation

6.1.1 Controller

Item	Criteria	Controller Options: PC or PLC
1	Evaluate Level of Corrosion	PCs rate a positive while PLCs rate a negative. PCs are better suited to evaluating the level of corrosion than PLCs. PCs are designed to work with imaging devices while PLCs are not. PLCs are primarily designed to work with discrete and analog industrial components.
2	Safety Concerns	PCs and PLCs rate as not applicable. There are no safety concerns associated with PCs and PLCs.
3	Ease of Use	PCs and PLCs rate a satisfactory, and are both easy to use and well known by the Electronics Lead's team.
4	COTS Component	PCs and PLCs rate a satisfactory, and are both considered COTS components.
5	JASPER Standard	PCs and PLCs rate a satisfactory, and are both considered standard components.
6	Component Size	PCs and PLCs rate as not applicable. There are no component size concerns, since they can be connected to the imaging components with a cable.

6.1.2 Human Machine Interface (HMI)

Item	Criteria	HMI Options: LabVIEW or C++
1	Evaluate Level of Corrosion	LabVIEW and C++ rate a satisfactory, and are both capable of performing the analysis required to evaluate the level of corrosion.
2	Safety Concerns	LabVIEW and C++ rate as not applicable. There are no safety concerns associated with LabVIEW and C++ programming languages.
3	Ease of Use	LabVIEW rates a positive while C++ rates a negative. The HMI development interface and image manipulation features in LabVIEW make it easier to use and maintain then C++ for this application.
4	COTS Component	LabVIEW and C++ rate a satisfactory, and are both considered COTS tools.
5	JASPER Standard	LabVIEW and C++ rate a satisfactory, and are both considered standard tools.
6	Component Size	LabVIEW and C++ rate as not applicable. There are no component size concerns, since they are programming languages.

6.1.3 File Storage

Item	Criteria	File Storage Option: PC
1	Evaluate Level of Corrosion	PCs rate a positive, and can perform the file storage tasks required to evaluate the level of corrosion.
2	Safety Concerns	PCs rate as not applicable. There are no safety concerns associated with PCs.
3	Ease of Use	PCs rate a positive, and are easy to use and well known by the Electronics Lead's team.
4	COTS Component	PCs rate a satisfactory, and are considered COTS components.
5	JASPER Standard	PCs rate a satisfactory, and are considered standard components.
6	Component Size	PCs rate as not applicable. There are no component size concerns, since it can be connected to the imaging components with a cable.

6.1.4 Imaging Components

6.1.4.1 Standard Imager

Item	Criteria	Standard Imager Option: CCD Image Array
1	Evaluate Level of Corrosion	CCD Image Arrays rate a positive, and are capable of recording the data necessary to evaluate the level changes in color and surface finish to the plutonium target.

Item	Criteria	Standard Imager Option: CCD Image Array
2	Safety Concerns	CCD Image Arrays rate a satisfactory, and are considered to have minimal safety concerns.
3	Ease of Use	CCD Image Arrays rate a positive. An image array is required to take a full field-of-view image of the plutonium target, see images of an example surrogate target in figure 16.
4	COTS Component	CCD Image Arrays rate a satisfactory, and are considered COTS components.
5	JASPER Standard	CCD Image Arrays rate a satisfactory, and are considered standard components.
6	Component Size	CCD Image Arrays rate a satisfactory, and are small devices.

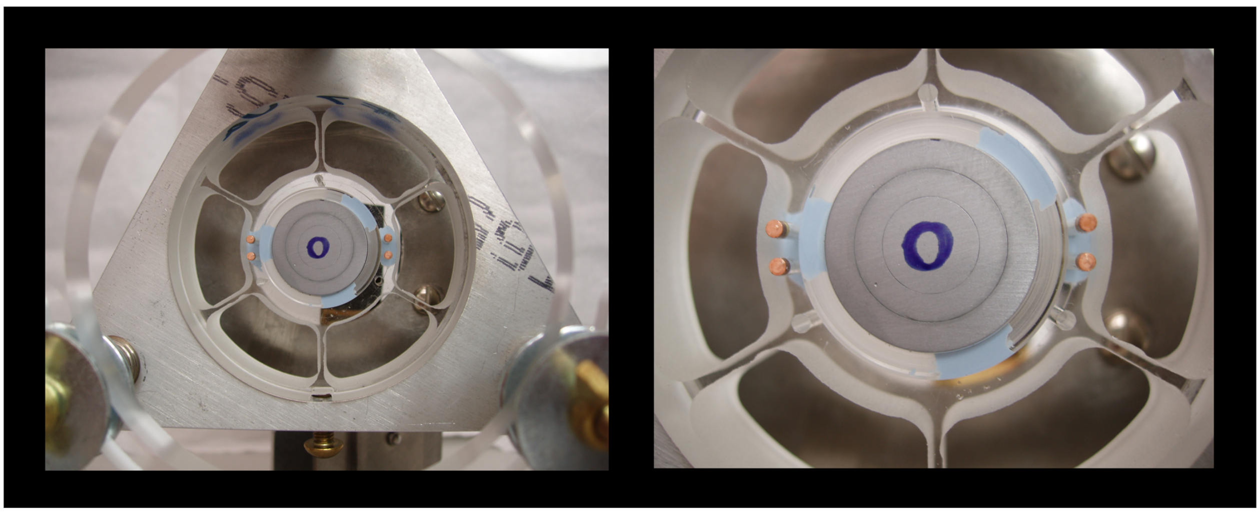


Figure 16: Example Surrogate Target

6.1.4.2 Standard Flash

Item	Criteria	Standard Flash Option: White Light
1	Evaluate Level of Corrosion	The White Light flash rates a positive, because it is the type of flash necessary to see changes in color and surface finish.
2	Safety Concerns	The White Light flash rates a satisfactory, because it has minimal safety concerns.
3	Ease of Use	The White Light flash rates a positive, because it is a very simple device.
4	COTS Component	The White Light flash rates a satisfactory, and is considered a COTS component.
5	JASPER Standard	The White Light flash rates a satisfactory, and is considered a standard component.
6	Component Size	The White Light flash rates a positive, because it can be a very small device.

6.1.4.3 Light-Scatter Imager

Item	Criteria	Light-Scatter Imager Options: CCD Image Array or CCD Linear Array
1	Evaluate Level of Corrosion	CCD Image Arrays and CCD Linear Arrays rate a satisfactory, and are both capable of recording the data necessary to evaluate the level of corrosion.
2	Safety Concerns	CCD Image Arrays and CCD Linear Arrays rate a satisfactory, and both are considered to have minimal safety concerns.
3	Ease of Use	CCD Linear Arrays rate a positive while CCD Image Arrays rate a negative. The light scatter patterns are symmetrical, as can be seen from figure 17, and it should be easier to analyze a slice through the center of the scatter pattern than the whole pattern.
4	COTS Component	CCD Image Arrays and CCD Linear Arrays rate a satisfactory, and are both considered COTS components.
5	JASPER Standard	CCD Image Arrays and CCD Linear Arrays rate a satisfactory, and are both considered standard components.
6	Component Size	CCD Image Arrays and CCD Linear Arrays rate a satisfactory, and are both small devices.

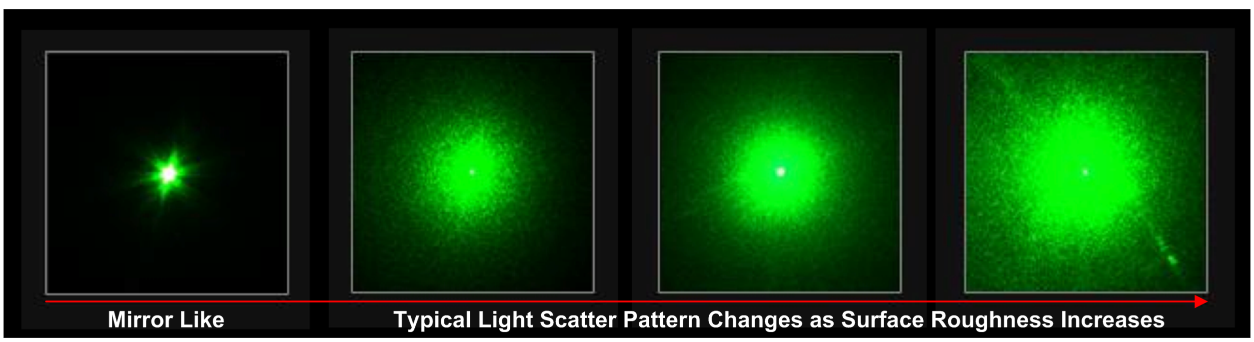


Figure 17: Example Laser Light Scatter Pattern

6.1.4.4 Light-Scatter Flash

Item	Criteria	Light-Scatter Flash Options: White Light, LED, or Laser
1	Evaluate Level of Corrosion	The Laser flash rates a positive, because it is intense and it generates coherent light. The LED flash rates satisfactory, because it is less intense than a laser and can generate coherent light. The White Light flash rates a negative, because it is less intense than a LED and it is incoherent.

Item	Criteria	Light-Scatter Flash Options: White Light, LED, or Laser
2	Safety Concerns	The LED flash and White Light flash rate a satisfactory, because they both have minimal safety concerns. The Laser flash rates a negative, because it may be an eye-safety hazard that may require engineered and administrative safety mitigations.
3	Ease of Use	The LED flash and White Light flash rate a positive, because they are very simple devices. The Laser flash rates a satisfactory, because it is a familiar component.
4	COTS Component	The Laser flash, LED flash, and White Light flash all rate a satisfactory, and are all considered COTS components.
5	JASPER Standard	The Laser flash, LED flash, and White Light flash all rate a satisfactory, and are all considered standard components.
6	Component Size	The LED flash and White Light flash rate a positive, because they are both very small devices. The Laser flash rates a negative, because depending on the intensity required, it may be too large and may require a fiber optic cable to implement.

6.2 Component Selection

For components that have multiple options, the component evaluation criteria and grades are summarized in a Pugh Diagram shown in figure 18. The identified selections for components are shown in yellow.

Component ►	Light Scatter Imager		Light Scatter Flash			Controller		Human Machine Interface (HMI)	
Criteria ▼	CCD Image Array	CCD Linear Array	White Light	LED	Laser	PC	PLC	LabVIEW	C++
Evaluate Level of Corrosion	S	S	-	S	+	+	-	S	S
Safety Concerns	S	S	S	S	-	NA	NA	NA	NA
Ease of Use	-	+	+	+	S	S	S	+	-
COTS Component	S	S	S	S	S	S	S	S	S
JASPER Standard	S	S	S	S	S	S	S	S	S
Component Size	S	S	+	+	-	NA	NA	NA	NA
Positive Sumation Σ+	0	1	2	2	1	1	0	1	0
Satisfactory Sumation ΣS	5	5	3	4	3	3	3	3	3
Negative Sumation Σ−	1	0	1	0	2	0	1	0	1

Figure 18: Pugh Diagram for the Selection of Components with Multiple Options

7.0 Proposed System Operational Architecture

The TCI system will have a mechanical mounting fixture that houses the TCI system's imaging components and provides the User with the ability to manually align the imaging components onto the plutonium target located inside the Target Assembly, which may also be located inside the PTC assembly. At this time, the mechanical mounting fixture's design is TBD (see section 3.2.1). The TCI system's imaging components are:

- CCD Image Array - used to take standard images.
- White Light Flash - used as the light source for standard images.
- CCD Linear Array - used to take light-scatter images.
- LED Flash - used as the light source for light-scatter images.

The TCI system will have a PC that will be used as the controller, file storage system, and as the platform that executes the LabVIEW HMI. The PC will allow the User to interact with the TCI system's imaging components. The combination of the PC controller, PC file storage, and LabVIEW HMI, will allow the User to perform the TCI system's three basic inspection functions: Take Alignment Images, Take Images (&TID), and Compare Selected Images (&TID). The proposed physical architecture diagram is shown in figure 19 and the proposed functional architecture diagram is shown in figure 20.

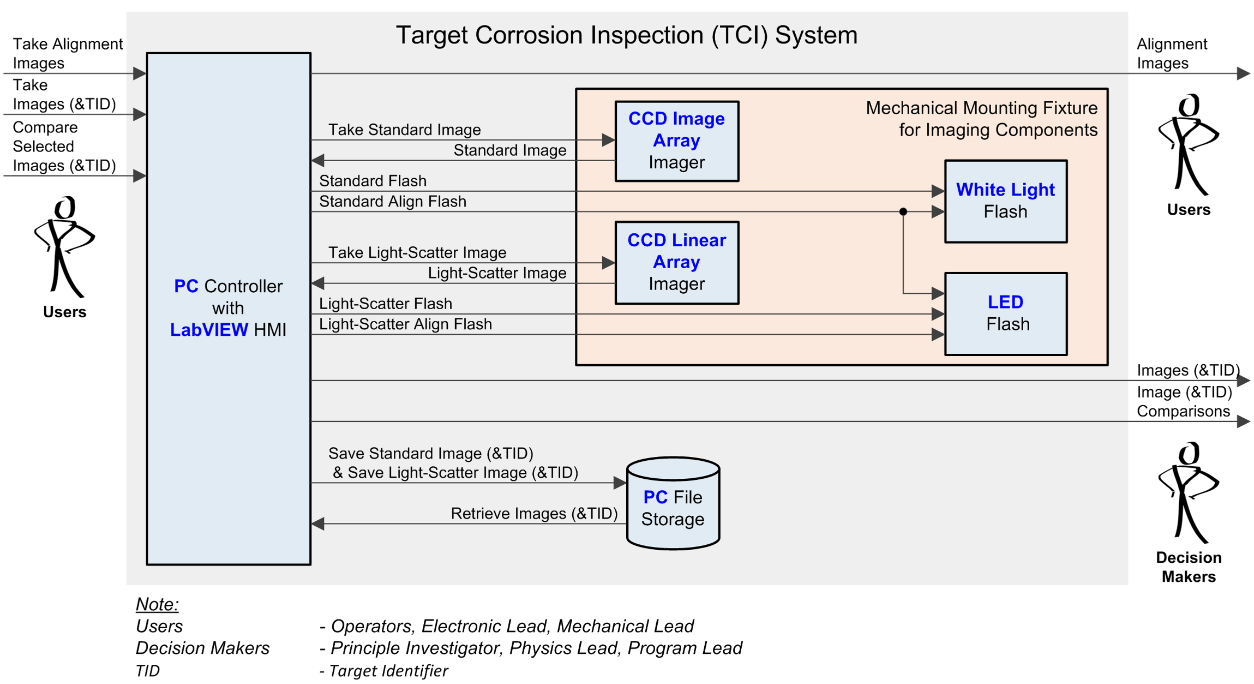
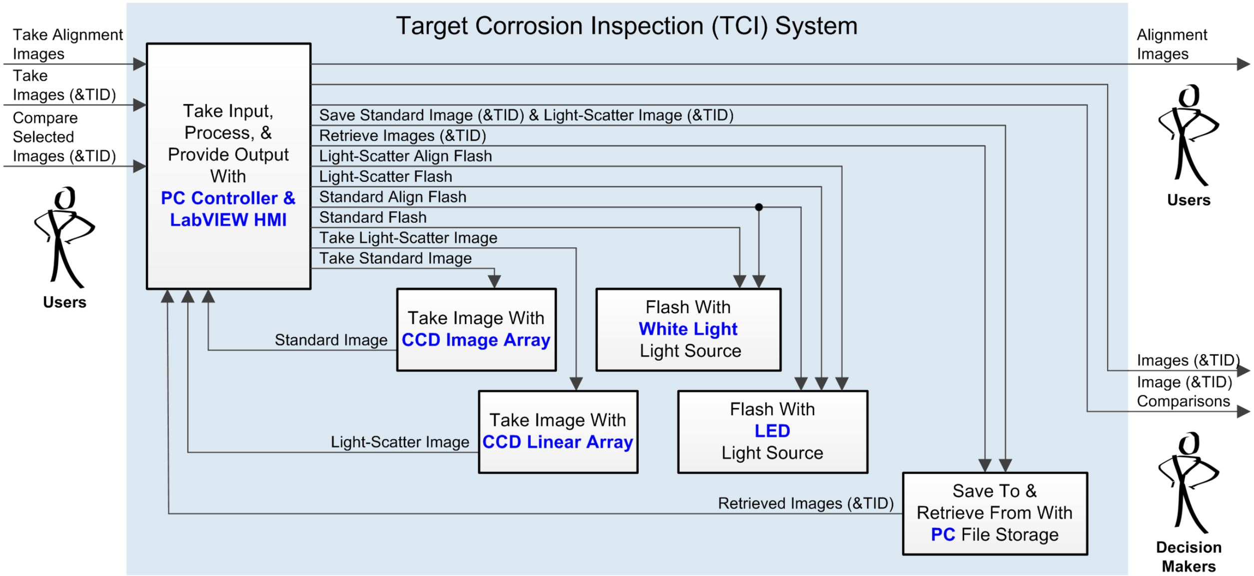


Figure 19: Proposed Physical Architecture Diagram



Note:
Users - *Operators, Electronic Lead, Mechanical Lead*
Decision Makers - *Principle Investigator, Physics Lead, Program Lead*
TID - *Target Identifier*

Figure 20: Proposed Functional Architecture Diagram

8.0 System Requirements

NOTE: Throughout this section the word “shall” is used to indicate an absolute system requirement, and the word “should” is used to indicate a discretionary system requirement.

The following list of requirements is only a first-cut and is not considered complete. This list of requirements is based on the active stakeholder’s initial expectations of the TCI system.

Item	System Requirement	Stakeholder Expectation
1	The TCI system shall mitigate Plutonium contamination from migrating into the SCC.	Expectation #1 from all stakeholders and agreed to by all as the system’s one **Sacred Expectation**.
2	The TCI system shall meet all LLNL Environment, Safety, and Health (ES&H) rules.	Expectation #2 from the Operators that is also a regulatory expectation.

Item	System Requirement	Stakeholder Expectation
3	The TCI system shall perform all LLNL Engineering Design Reviews.	Expectation #3 identified by the Operators (ease of use) that is also an LLNL Engineering quality assurance expectation. Design reviews keep all stakeholders apprised of the system design while also allowing them to provide feedback on design issues.
4	The TCI system shall take a color image of the plutonium target for visual evaluation of the changes to the plutonium target's surface color and finish.	Expectation #2 from the Program Lead that supports the sacred expectation.
5	The TCI system shall take a light-scatter image of the plutonium target for analytical evaluation of the changes to the plutonium target's surface roughness.	Expectation #2 from the Physics lead that supports the sacred expectation.
6	The TCI system's light-scatter imager shall be able to resolve a surface roughness in the range of 0.1μm (polished surface) to 5.0μm (corrosion dust forming on surface).	Expectation #1 & #2 from the Mechanical Lead was the basis for generating the surface roughness resolution that supports the sacred expectation.
7	The TCI system shall have a mechanical mount point for all imaging components that provides repeatable results.	Expectation #6 from the Mechanical Lead that supports the sacred expectation.
8	The TCI system shall view the target through the sapphire window in the Target Assembly VAT valve.	Expectation #3 from the Mechanical Lead that is also a physical constraint.
9	The TCI system shall be able to mount to the Target Assembly and function, prior to the Target Assembly being assembled in the PTC.	Expectation #4 from the Mechanical Lead that is also a physical constraint.
10	The TCI system shall be able to mount to the PTC assembly and function, after the Target Assembly has been assembled in the PTC.	Expectation #5 from the Mechanical Lead that is also a physical constraint.
11	The TCI system's imaging components shall be able to fit through the PTC's Alignment Access Port, after the Target Assembly has been assembled into the PTC.	Expectation #7 from the Mechanical Lead that is also a physical constraint.
12	The TCI system shall meet the operational 1-hour access time for a Pre-Shot inspection.	Operational expectation identified by stakeholders in a timeliness meeting.
13	The TCI system shall meet the operational 4-hour analysis time for a Pre-Shot inspection.	Operational expectation identified by stakeholders in a timeliness meeting.

Item	System Requirement	Stakeholder Expectation
14	The TCI system should maximize the quality of physics data.	Expectation #2 identified by the Principal Investigator, Mechanical Lead, and Physics Lead.
15	The TCI system should use commercial-off-the-shelf (COTS) electronic components.	Expectation #2 identified by the Electrical Lead.
16	The TCI system should use standard JASPER systems and tools (such as: computers, PLCs, scopes, programming languages, etc.).	Expectation #3 identified by the Electrical Lead.

9.0 Organizational and Business Impact

The TCI system has no legacy implementation. The JASPER facility has never had the capability that the TCI system is envisioned to provide. The legacy process was to do nothing and hope that the facility's design engineers had designed enough mitigative features into the system to prevent plutonium contamination from propagating into the SCC. Since that was clearly not the case, the current JASPER management has directed that the TCI system provide additional mitigative features.

There is no expected organizational impact associated with the TCI system, but there are two business impacts that are related to JASPER Operations:

1. The impact to the JASPER shot operations timeline has been identified in figure 14, and this should include the operational constraints in section 4.2.2 associated with pre-shot inspection timeliness.
2. The impact to shot operations based on pre-shot knowledge of the plutonium target's status is anticipated to be extremely beneficial.

10.0 Risks and Technology Readiness Assessment

All of the technology that is covered in this document has been used before in diagnostics that have been implemented for experimental facilities at LLNL. The following are risks that have been identified for the TCI system:

10.1 Manual Alignment Takes Too Long

The possibility that the manual alignment may take too long has been identified as a possible risk to the TCI system that we need to plan for. It is possible to minimize the number of alignment steps required by fixing the positions of the imagers and only aligning the light sources. If this solution does not work out, then the best option is to work with the Mechanical Lead and design a mechanical fixture that is pre-aligned. Implementing a TCI mechanical fixture that is pre-aligned will require the plutonium target inside the Target Assembly to be precisely located so that it is always in the same place. A precisely located target may require mounting fixture modifications and assembly procedure modifications.

10.2 LED Flash is Not Intense Enough for Light-Scatter Imaging

The possibility that the LED flash is not intense enough for taking a light-scatter image has been identified as a possible risk to the TCI system that we need to plan for. The LED should produce enough light to take a light-scatter image, but there is the possibility that we will need a more intense light source to resolve the light-scatter pattern. The best solution is to use a laser as the light-scatter flash. Unfortunately, this will require evaluating the eye-safety hazards as well as implementing engineered and administrative safety mitigations. Using a laser is not impossible, since laser systems are used in almost all of our experimental facilities. Using a laser is a complication we wish to avoid.

10.3 Imaging Component Sizes are Too Large

The possibility that the imaging component sizes are too large has been identified as a possible risk to the TCI system that we need to plan for. If we need to replace the LED with a Laser, the laser is likely to be too large to fit through the PTC Alignment Access. The solution, in this situation, is to move the large imaging component outside the PTC and use fiber optic cables and lenses to transmit the flash light source to the target, or to transmit the field of view back to the imager.

11.0 Acronyms and References

11.1 Acronyms

CCD	– Charge-Coupled Device
COTS	– Commercial Off The Shelf
DOD	– Department Of Defense
DOE	– Department Of Energy
DS	– Diagnostic System
ES&H	– Environment, Safety, and Health
HEPA	– High-Efficiency Particulate Arrestment
HMI	– Human Machine Interface
JASPER	– Joint Actinide Shock Physics Experimental Research
LED	– Light Emitting Diode
LLNL	– Lawrence Livermore National Laboratory
NNSA	– National Nuclear Security Administration
NNSS	– Nevada National Security Site (formerly NTS)
NTS	– Nevada Test Site (currently NNSS)
PC	– Personal Computer
PLC	– Programmable Logic Controller

PTC – Primary Target Chamber
SCC – Secondary Confinement Chamber
SSP – Stockpile Stewardship Program
TA – Target Assembly
TBD – To Be Determined
TCI – Target Corrosion Inspection
TID – Target Identifier
UCV – Ultrafast Closure Valve
VAT – A company name, and a synonym for vacuum gate valve

11.2 References

- Haschke, J.M., T.H. Allen, and L.A. Morales, 2000, "Surface and Corrosion Chemistry of Plutonium", Los Alamos Science, Number 26, Page 252.